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Zoopharmacognosy

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CHAPTER

Folklore asserts that animals instinctively know how to medicate their ills from the herbs they find growing wild. Traditional herbalist Juliette de Bairacli Levy writes that sick animals partake "only of water and the medicinal herbs which inherited intelligence teaches it instinctively to seek." Around the world, traditional herbalists use observations of sick wild animals to find new medicines. Benito Reyes of Venezuela, for example, claims to have discovered the antiparasitic benefits of the highly astringent seeds of the Cabalonga tree *(Nectandra pinchurim)* by observing emaciated animals scraping and chewing the fallen seeds.

As a result of such folklore, there is a common lay assumption that animals unerringly know which herbs to use for which ills. However, this overly romantic view of the wisdom of an all-knowing animal is clearly incorrect. Both wild and domestic animals are known to poison themselves by feeding on toxic substances, repeatedly return to feed on toxic but intoxicating plants, and sometimes quite clearly fail to successfully medicate their ills. Such failures could suggest that animals are in fact incapable of helping themselves when ill and have in the past kept the topic of animal self-medication off the research agenda.

However, a growing body of scientific evidence shows that animals—not only mammals but birds and insects—are self-medicating a variety of physical and psychological ills. Such behavioral strategies though, like all strategies, are fallible; however, it is the limits of efficacy that are of great interest to those working in the field of animal health. Because self-medication strategies have the potential to greatly enhance the health of animals in our care, we would be wise to explore them more closely.

SELF-REGULATION

Living systems are inherently self-regulatory. Behavior is one means by which animals regulate their physiologic and psychological states. For example, overheated animals move into the shade, where it is cooler; dehydrated, they search for water; anxious, they seek safety. However, behavioral self-regulation is far more refined than this. Deprived of only one amino acid, rats increase their consumption of novel foods until they find a diet that is rich in that missing amino acid. Furthermore, they learn an aversion to foodstuffs that are deficient in only one amino acid (Rogers, 1996; Fuerte, 2000). Lambs monitor the carbohydrate and protein content of their diet and adjust their feeding accordingly. If deprived of phosphorus, sheep not only identify a phosphorus-rich diet but also learn a preference for the foods that correct deficiency malaise (Villalba, 1999; Provenza, 1995).

Reviewers conclude that such nutritional wisdom is achieved via a combination of postingestive hedonic feedback and individual learning. They propose that "behavior is a function of its consequences" (Provenza, 1995, 1998). This is true of health maintenance in general, that is, the individual assesses via hedonic feedback—"Do I feel better or worse after doing that?"

The cost to an individual of not maintaining health can be high. Consequently, natural selection has honed a variety of behavioral health maintenance strategies reviewed most recently by Hart (1990, 1994) and Huffman (1997a). As Hart points out, behavior is often the *first line of defense* against attack by pathogens and parasites. As a result, animals use behavioral strategies for avoiding, preventing, and therapeutically addressing threats to survival.

NATURE'S LARDER—POWERFUL PHARMACOPOEIA

Animals must obtain the nutrients and energy they need from a larder that is constantly changing in composition and is often well defended. Moreover, nutrients and energy often come packaged with varying quantities of nonnutrients, many of which are bioactive. This bioactivity is not a fixed phenomenon either. These nonnutrients can be toxic, intoxicating, or medicinal, depending on dose, frequency of consumption, and combination with other foodstuffs, as well as on the changing internal conditions of individual animals.

Priority is given to finding sufficient nutrients and energy without consuming too many toxic defensive compounds. Adaptive taste preferences and biochemical detoxification processes help in this regard. The task requires not only adaptive physiologic characteristics but also continuous self-regulation at the behavioral level. A food that is safe on one occasion may be unsafe on another. The postingestive effects of each feeding bout must be monitored, so that survival is not threatened. Put simply, foods that create unpleasant sensations are avoided, those that create pleasant sensations or remove unpleasant sensations such as deficiency malaise are preferred.

As animals use hedonic feedback to find ways of remedying the unpleasant sensations of dietary deficiencies, and of avoiding the worst chemical defenses of plants and insects foods, so they can also find ways of removing the unpleasant sensations of disease and injury.

Early research on insects distinguished normal feeding from pharmacophagy (Boppre, 1984). Further refinement included a new term—zoopharmacognosy—that described the discoveries of animals who were apparently using medicinal herbs to treat illness (Rodriguez, 1993).

Huffman described a set of conditions that would help primatologists discriminate self-medication from normal feeding in wild primates. First, the animal should show signs of being ill (preferably with some quantifiable test as evidence of sickness). Second, it should seek out and consume a substance that is not part of its normal diet and that preferably should have no nutritional benefit. Its health should then improve (again, established quantifiably by tests) within a reasonable time, commensurate with the known pharmacology of the substance. Laboratory analysis of the plant or substance is then needed to establish that the amount consumed contains enough active ingredients to bring about the changes observed.

Although these criteria are helpful for identifying possible instances of self-medication in the field, they do not define self-medication. As we shall see, recent research on various animal species (both wild and domesticated) illustrates the broad spectrum of approaches that animals use to self-medicate.

Wild Medicine—Beneficial Diets

Everyday diets include beneficial nonnutritional components. A few of many possible examples are described here.

In the rain forests of Costa Rica, mantled howler monkeys are infested with different quantities of internal parasites, depending on where they live. Those living in La Pacifica have high levels of parasites, and those living in Santa Rosa have low levels. None of the heavily infested group has access to fig trees *(Ficus* spp*)*, but the less infested group has many fig trees available. South Americans traditionally use fresh fig sap to cure themselves of worms because the sap decomposes worm proteins (Stuart, 1990; Strier, 1993; Glander 1994).

In the Fazenda Montes Claros Park in southeastern Brazil, endangered muriquis (or woolly spider monkeys) and brown howler monkeys are completely free of all intestinal parasites—a startling and unexpected discovery. In another location, both species are infested with at least three species of intestinal parasites. The main difference between monkeys in the two locations is that the worm-free monkeys have access to a greater selection of plants used as anthelmintics by local Amazonian people (Stuart, 1993).

The everyday diet of great apes contributes much to the sustainable control of parasites. Chimpanzees at Mahale Mountains National Park, for example, eat at least 26 plant species that are prescribed in traditional medicine for the treatment of internal parasites or the gastrointestinal upset that they cause (Huffman, 1998).

In Brazil, the gold and red maned wolf roams the forest at night hunting small prey but taking up to 51% of its diet from plants. By far, its favorite is the tomato-like fruit of Lobeira, or Wolf's fruit *(Solanum lycocarpum)*. Although these fruits are more plentiful at certain times of year, the wolf works hard to eat a constant amount throughout the year, suggesting that this fruit is of some significant value. Researchers at Brazilia Zoo found that they could not help their captive wolves survive infestation with a lethal endemic giant kidney worm unless they fed Lobeira daily to their packs (daSilveira, 1969).

Correlations have been noted too in domestic diets and worm loads. When commercially raised deer in New Zealand were grazed on forage containing tannin-rich plants such as chicory, farmers needed to administer less chemical de-wormer (Hoskin, 1999). Furthermore, given a choice, parasitized deer and lambs select the bitter and astringent Puna chicory, thereby reducing their parasite load (Schreurs, 2002; Scales, 1994). Tannin-rich plants such as this are commonly selected in moderate amounts by free-ranging animals. Researchers in Australia and New Zealand have found that certain types of forage such as *Hedysarum coronarium, Lotus corniculatus,* and *L. pedunculatus,* which contain more useful condensed tannins, can increase lactation, wool growth, and live weight gain in sheep, apparently by reducing the detrimental effects of internal parasites (Aerts, 1999; Niezen, 1996). Tannin-rich pastures may also provide opportunities for ungulates to regulate bloat (McMahon, 2000).

Occasionally, even extra large doses of astringent tannins may be consumed. Janzen described how the Asiatic two-horned rhinoceros occasionally eats so much of the tannin-rich bark of the mangrove *Ceriops candolleana* that its urine turns dark orange. He postulated that the rhinoceros may be self-medicating against endemic dysentery, pointing out that the common antidysentery medicine—clioquinol (Enterovioform)—consists of about 50% tannin (Janzen, 1978).

Adaptive Taste Preferences

Evidence suggests that animals seek out particular tastes because of the adaptive consequences. Tannins usually deter mammals from eating plants because their astringency puckers and dries the tongue and impairs digestion by binding proteins. However, as we have seen, tannins

are not avoided entirely. Given a choice, deer avoid selecting food with the lowest tannin levels and instead select those containing moderate amounts, suggesting that a certain amount of tannin is attractive to them (VerheydenTixier, 2000). It appears such taste preferences may be adaptive because of the impact of tannins on intestinal parasites. When domesticated goats were fed polyethylene glycol (PEG), which deactivates tannins, numbers of intestinal parasites increased (Kabasa, 2000). Sheep, goats, and cattle increase tannin consumption when fed the deactivating PEG. Alternatively, when fed high-tannin diets, lambs increase PEG intake (Provenza, 2000). These results indicate an attempt to self-regulate tannin consumption to an optimal level.

As we shall see in the next section, other so-called feeding deterrents are sought out when their potent bioactive effects outweigh taste aversions.

Bioactive Botanicals—Toxin or Medicine?

Chimpanzees have similar taste preferences to humans. They prefer sweet over bitter foods. In the Mahale Mountains of Tanzania is a small shrub, *Vernonia amygdalina,* known as bitter leaf. Its extreme bitterness successfully keeps most indigenous animals away, although introduced domesticated goats appear unable to identify the risks; consequently, another common name for this plant is "goat killer." When local chimpanzees are sick, they seek out this bitter, toxic plant, carefully strip off the outer layers of shoots, and chew and suck the juicy bitter pith.

The plant is considered a very strong medicine by local people who use it to treat malarial fever, stomachache, schistosomiasis, amoebic dysentery, and other intestinal parasites (Huffman, 1989). Pig farmers in Uganda supply their animals with branches of this plant, in limited quantities, to treat intestinal parasites.

Bitter pith chewing is rare, but chimpanzees with diarrhea, malaise, and nematode infection recover within 24 hours (similar to the recovery time of local Tongwe people who use this medicine). The behavior clearly influences nodular worm infestation. In one example, fecal egg count dropped from 130 to 15 nodular worm eggs within 20 hours of chewing bitter pith. Bitter pith chewing is more common at the start of the rainy season, when nodular worms increase (Huffman, 1997b) (Figure 2-1). Furthermore, scientists have noticed that chimpanzees with higher worm loads, or those that appear to be more ill, tend to chew *more* bitter pith than those with lower infestation levels.

Vernonia amygdalina from Mahale contains seven steroid glucosides, as well as four sesquiterpene lactones, capable of killing parasites that cause schistosomiasis, malaria, and leishmaniasis. The sesquiterpene lactones (previously known to chemists as "bitter principles") are not only anthelmintic but also antiamoebic, antitumor, and antimicrobial. The outer layers of the shoots and leaves of the shrub, which chimpanzees so carefully discard, contain high levels of vernonioside B1 that would be extremely toxic to a chimpanzee. Not only can chimpanzees find a suitable plant to alleviate their symptoms, they can also find the right *part* of the plant to be effective without harm (Ohigashi, 1991, 1994).

Figure 2-1 Chimpanzee sucks on the bitter pith of *Vernonia amygdalina* (bitter leaf) in Tanzania. *(Courtesy Michael Huffman.)*

It is possible that bitterness in plants may be an effective indicator of medicinal properties: it generally indicates toxicity, but it is this very toxicity that is so effective against parasites. This plant is not just bitter, it is the most bitter plant the chimpanzees can find in the forest. One slurp of its juice will make an adult human wince. Chimpanzees and other animals normally avoid it, but appetitive or tolerance changes may take place during sickness. Sick human patients will apparently tolerate more bitter herbal prescriptions, but as health improves, their tolerance of bitters declines. The mechanism that brings about these changes is not yet known, but experimental evidence supports the idea of an adaptive taste preference for bitters.

Laboratory mice were used to explore the link between illness and consumption of bitters. Experimental mice were given a choice between two water bottles—one contained only water, and the other, a bitter-tasting chloroquine solution that would combat malarial infection. Control mice were given only water. Those mice infected with malarial parasites and given access to chloroquine experienced significantly less infection and mortality than did infected mice with no access to chloroquine. Malarial infection was reduced because mice took approximately 20% of their water from the bottle containing the bitter chloroquine solution. However, consumption of chloroquine was not related to malarial infection. Given a choice, both sick and nonsick mice took small doses of the bitter solution, supporting the idea of an adaptive taste preference for moderate consumption of bitters (Vitazkova, 2001).

It is not only primates, or even vertebrates, that use herbal medicines to control parasites. Even insects do it.

It has long been known that certain butterflies harvest and store the toxic cardiac glycosides from milkweed plants, and that this stash protects them against some predatory birds. However, these glycosides also protect butterfly larvae from internal parasites. It is not clear whether these benefits are merely incidental to feeding, yet the dietary choice is distinctly beneficial.

Scientists who study insect parasitoids (lethal parasites) have found convincing evidence that insects do self-medicate. Woolly bear caterpillars of the tiger moth can be injected with the eggs of parasitic tachinid flies. Fly larvae develop inside the caterpillars, feeding off their fat reserves and finally bursting out of the abdominal wall. Under laboratory conditions, infected caterpillars usually die from this experience. However, when Richard Karban and his colleagues at University of California Davis started rearing their caterpillars in outdoor enclosures, they noticed that the survival rate of parasitized caterpillars was much higher. Outside, the caterpillars had access to plant species not provided in the laboratory. Given a choice, healthy caterpillars chose to feed on lupine *(Lupinus arboreus),* and parasitized caterpillars preferred to feed on hemlock *(Conium maculatum)*. Having parasites affected dietary choices, and the change in diet improved chances for survival. Although hemlock, which is known to contain at least eight alkaloids, does not kill the parasites, it helps caterpillars survive infection (Karban, 1997).

Geophagy

Geophagy—the consumption of soil, ground-up rock, termite mound earth, clay, and dirt—is extremely common in mammals, birds, reptiles, and invertebrates. The habit is still found among many contemporary indigenous peoples, including the Aboriginal people of Australia and the traditional peoples of East Africa and China (Abrahams, 1996).

Geophagy is far more common in animals that rely predominantly on plant food and is more common in the tropics. Historically, the explanation for geophagy was that animals ate earth for the purpose of gaining minerals, such as salt (sodium chloride), lime (calcium carbonate), copper, iron, or zinc. Certainly, wild animals do seek minerals from natural deposits, but a need for minerals is by no means a universal explanation for geophagy. There are many cases in which the soils eaten are not rich in minerals; they sometimes even have *lower* levels of minerals than the surrounding topsoil. Recent geophagy research indicates that the small particle clay profile of soil is often the prime reason for geophagy.

In the body, clays can bind mycotoxins (fungal toxins), endotoxins (internal toxins), manmade toxic chemicals, and bacteria, and they can protect the gut lining from corrosion, acting as an antacid and curbing diarrhea. In short, clay is an extremely useful medicine.

The benefits of clay to animal health have been known for some time. Addition of bentonite clay improves food intake, feed conversion efficiency, and absorption patterns in domestic cattle by 10% to 20%. Clay-fed cattle also experience less diarrhea and fewer gastrointestinal ailments (Kruelen, 1985). In addition, veterinarians find clay an effective antacid. Free-ranging cattle help themselves to clay by digging out and licking at subsoils.

High in the Virunga Mountains of Rwanda, mountain gorillas mine yellow volcanic rock from the slopes of Mount Visoke. After loosening small pieces of rock with their teeth, they take small lumps in their powerful leathery hands and grind them to a fine powder before eating (Schaller, 1964). Gorillas are more likely to mine rock in the dry season, when they are forced to change their diet to plants such as bamboo, *Lobelia,* and *Senecio*, which contain more toxic plant secondary compounds than are found in their usual diet. Along with this change in diet comes diarrhea (a natural response to rid the body of toxins); this extra loss of fluid during the dry season could be a serious health problem for the gorilla (Fossey, 1983). Halloysite, the type of clay found in the subsoil eaten by mountain gorillas, is similar to kaolinite, the principal ingredient in Kaopectate, the pharmaceutical commonly used to soothe human gastric ailments. Kaolinite helps reduce the symptoms of diarrhea by absorbing fluids within the intestine (Mahaney, 1995).

Wild chimpanzees take regular mouthfuls of termite mound soil and scrape subsoils from exposed cliff faces or river banks. When scientists spent 123 hours looking specifically at the health of chimpanzees eating termite mound soil, they found that all were unwell, with obvious diarrhea and other signs of gastrointestinal upset (Mahaney, 1996). Analyses of termite mound soils show them to be low in calcium and sodium but high in clay (up to 30%), more specifically, in the same sort of clay used by mountain gorillas and sold by human chemists to treat gastrointestinal upsets in the West. Termite mound soils are used not only by chimpanzees but also by many other species, such as giraffes, elephants, monkeys, and rhinoceroses.

In the rain forests of the Central African Republic, forest elephants and other mammals have created large treeless licks on outcrops of ancient subsoils (Figure 2-2). Most are high in minerals, but almost a third of the licks have lower levels of minerals than surrounding soils. The one thing *all* the sites have in common is a clay content of over 35%. These elephants feed primarily on leaves all year round, except for 1 month—September—when ripening fruit is so abundant that they change to eating mainly fruits. Leaves generally contain defensive secondary compounds to deter herbivores; ripe fruits do not. A change from eating leaves to fruits would therefore dramatically reduce the consumption of toxic secondary compounds—a natural experiment to see whether toxin consumption equates with clay consumption. The only month in which elephants reduce their visits to the clay licks is during that fruit-eating month—September (Klaus, 1998)!

In the tropical forests of South America, too, clay consumption is particularly common in parrots, macaws, monkeys, tapirs, peccaries, deer, guans, curassows, and chachalacas. After studying geophagy in the Amazon forest of Peru for many years, Charles Munn concluded that nearly *all* vertebrates that feed on fruits, seeds, and leaves also eat clay. On an average day, he has observed

Figure 2-2 Elephants dig down to find clay deposits in Central Africa. *(Courtesy Martin Gruber.)*

up to 900 parrots from 21 species and 100 large macaws gathering to feed on the eroding riverbanks, biting off and swallowing thumb-sized chunks of orange clay (Mayer, 1999).

In 1999, the hypothesis that animals eat clay for the purpose of inactivating plant toxins was tested experimentally with macaws by James Gilardi and a team of scientists at the Davis California campus. First, they established that seeds eaten by macaws contain toxic plant alkaloids. Then, they fed one group of macaws a mixture of a harmless plant alkaloid (quinidine) plus clay. A second group of macaws were fed just the quinidine, without any clay. Several hours later, the macaws that ate the quinidine *with* clay had 60% less alkaloid in their blood than did the control group, demonstrating that clay can indeed prevent the movement of plant alkaloids into the blood. What surprised the scientists though was that the clay remained in the macaws' gut for longer than 12 hours, meaning that a single bout of geophagy could protect the birds for quite some time. It is suspected that clay not only prevents plant toxins from getting into the blood, but it also lines the gut and protects it from the caustic chemical erosion of seed toxins (Gilardi, 1999). Because macaws do not have a diarrheal response to toxins, the consumption of clay may be an essential part of their diet, allowing them to successfully use foods that other animals are unable to tolerate.

It is evident that clay is sought by many animals with gastrointestinal malaise—often caused by plant toxins but also by internal pathogens. In fact, eating clay is used as an *indicator* of gastrointestinal upset in rats (Takeda, 1993). Rats are unable to vomit, and when they are experimentally poisoned with lithium chloride, they eat clay; this "illness response behavior" is dose dependent, that is, the more sick they feel, the more clay they eat. If they are then given saccharin (a sweet taste) with the poison, they learn to associate the sweet taste with the feeling of nausea. They will then eat clay even when given saccharin alone (Sapolsky, 1998).

Scientists who research geophagy agree that, as a strategy, it has many benefits. The Director of the Geophagy Research Unit in Utah, William Mahaney, concludes, "All geophagy is a form of self-medication." Archaeological nutritionist Timothy Johns proposes that geophagy may be the earliest form of medicine and concludes that, although some soils can be a source of nutrients (minerals and/or trace elements), the primary benefit of clay consumption is its effect of countering dietary toxins and, secondarily, the effects of parasites. This explains why plant eaters need to eat earth, and why this practice is more common in the tropics, where plants are more heavily defended by toxic secondary compounds.

Mechanical Scours

Great apes (i.e., chimpanzees, bonobos, and gorillas) do something peculiar with hairy leaves. They assess a potential leaf with their hands, mouth, and tongue while it is still attached to the plant; then, if it is desirable, they pick it, fold it in concertina fashion, and swallow it whole without chewing (Figure 2-3). In each bout, apes swallow from one to one hundred leaves, which are later excreted undigested. Across Africa, they use leaves from at least 34 different species of herbs, trees, vines, and shrubs. Some contain bioactive phytochemicals, others do not; however, *all* are rough in surface texture with hooklike microstructures called *trichomes* (Wrangham, 1977; Huffman, 1997, 2003).

Leaf swallowing, as it is known, is more common at the beginning of the rainy season, when nodular worm infestation starts to increase; many of the apes seen doing this are clearly suffering from symptoms of nodular worm infestation, including diarrhea, malaise, and abdominal pain (Huffman, 1997). After decades of research, scientists discovered that the rough texture of leaves acts as a mechanical scour, scraping loose intestinal worms out through the gut. Rough leaves also stimulate diarrhea and speed up gut motility, helping the animal to shed worms and their toxins from the body. This is likely to provide rapid relief from feelings of gastrointestinal malaise (Huffman, 2001).

It seems that leaf swallowing is particularly effective against nodular worms because they move around freely in the large intestine looking for food and mates. Other worms (such as threadworms and whipworms) burrow into the mucosa of the small intestine and thereby probably escape the scraping effects of rough leaves. However, leaf swallowing has also helped chimpanzees at Kibale National Park, Uganda, to rid themselves of a particularly heavy outbreak of tapeworms *(Bertiella studeri)* (Wrangham, 1995).

It is thought that the unpleasant sensations of abdominal pain, diarrhea, and bowel irritation of nodular worm and tapeworm infestations could be the triggers for leaf swallowing or the chewing of bitter pith (Huffman, 1997).

Primates are not the only species to seek out mechanical scours. Biologists have long known that bears somehow rid themselves of internal parasites before hibernation. Alaskan brown bears in Katmai National

Figure 2-3 Chimpanzee selects hairy Aspilia leaf in Tanzania. *(Courtesy Michael Huffman.)*

Park change their diet before hibernation. Highly fibrous, sharp-edged, coarse sedge *(Carex* spp [Cyperaceae]*)* appears in large dung masses almost completely composed of long tapeworms. The coarse plant material scrapes out the worms in a similar way to the rough leaves swallowed by chimpanzees (Huffman, 1997). Physical expulsion also seems to be used by Canadian snow geese. Just before migration, they deposit large boluses of undigested grass and tapeworms in their dung. When they reach their migration destination, they are clear of tapeworms. In both brown bears and snow geese, worms are being shed at a time of critical nutritional stress—a time when carrying these parasites would greatly reduce the animal's chances of survival.

Wolves eat grass, and wolf scats have been found that contain both grass and roundworms (Murie, 1944). Tigers are reported to eat grass "when hungry," although if heavily infested with worms, they may appear emaciated. Samples of the droppings of wild Indian tigers consist almost entirely of grass blades, and in at least one case, a tapeworm was found inside (Schaller, 1967). Both domestic dogs and cats occasionally chew grass—possibly a residual self-medication strategy of their wild ancestors.

Traditional herbalists use physical scours as a method of worm control. With chemical de-wormers (herbal or nonherbal), there is a delicate balance between a dose toxic enough to harm the parasites yet not the host. These nontoxic physical remedies used by wild animals may be a particularly useful addition to parasite control in modern farming, where parasites are increasingly resistant to drugs (Huffman, 2003).

Figure 2-4 European starlings fill nest box with pungent herbs at hatching time. *(Courtesy Helga Gwinner.)*

Topical Applications

Birds and mammals also use nature's pharmacy externally on their skin and in their immediate environment. In these examples, they are exploiting the volatile components of plant and insect secretions.

During nesting time, male European starlings collect a selection of aromatic herbs to bring back to the nest (Figure 2-4). In North America, they preferentially select wild carrot *(Daucus carota),* yarrow *(Achillea millefolium),* agrimony *(Agrimonia parviflora),* elm-leaved and rough goldenrod *(Solidago* spp*),* and fleabane *(Erigeron* spp*),* even when they are not the most common plants nearby. These herbs are all highly aromatic. Furthermore, they contain more volatile oils, in greater concentrations, than are found in aromatic plants close at hand that are not selected.

Back at the nest, the fresh herbs are woven into the nest matrix and topped up all the while the chicks are hatching. The benefits of these herbs to the chicks are evident. Chicks in herb nests have a significantly greater chance of surviving into the next season than do chicks in nests from which the herbs have been removed (Clark, 1988).

Chicks do not eat or actively rub against these pungent herbs, yet when herbs are removed from nests, chicks become infested with more mites. More specifically, chicks in nests that contain wild carrot have higher hemoglobin levels than do those without, again suggesting that they are losing less blood to blood-sucking mites.

Preferred plants contain monoterpenes and sesquiterpenes (such as myrcene, pinene, and limonene) that are harmful to bacteria, mites, and lice in the laboratory. These herbs are particularly effective against the harmful bacteria *Streptococcus aureus, Staphylococcus epidermidis,*

and *Pseudomonas aeruginosa*. Lining the nest with pungent herbs is adaptive in that it has a number of different beneficial effects on chicks (Clark, 1985).

In Panama, white-nosed coatis, relatives of raccoons, rub their coats with resin from the *Trattinickia aspera* tree that has a camphor- or menthol-like smell. This resin is used by local Guaymi Indians to repel biting flies. Chemists at Cornell University have identified sesquiterpene lactones in the resin that are repellent to fleas, lice, ticks, and mosquitoes.

In the mosquito-ridden llanos of central Venezuela, wedge-capped capuchin monkeys rub the secretions of large millipedes into their skin. The active ingredients are benzoquinones, which are potentially carcinogenic but antimicrobial and repellent to insects such as the bothersome mosquitoes (Valderrama, 2000).

LABORATORY EXPLORATIONS OF SELF-MEDICATION

Although biologists were initially surprised by examples of self-medication observed in the field, the ability of animals to self-medicate has been used in laboratory experiments for many years. Self-selection of drugs is commonly used in pain, addiction, and mental health research.

Laboratory experiments show that mice actively self-medicate feelings of anxiety. In one example, one group of mice received electric shocks to the feet ("acute physical stress"), and the other group was forced to witness *another* mouse getting a foot shock ("acute emotional stress"). Both groups of mice had free access to morphine, but only the mice exposed to emotional stress self-administered the morphine (Kuzmin, 1996). A similar effect is seen with cocaine self-administration in emotionally stressed rats (Ramsey, 1993).

Scientists in the Ukraine found that stressed rats learned to self-administer strobe lighting at certain frequencies that changed electrical activity in the brain, thereby calming heart rhythm and lowering blood pressure. The rats thereby ingeniously calmed themselves down (Shlyahova, 1999). A feeling of anxiety is clearly unpleasant, and it is surely the animal's desire to *feel* better that drives this kind of behavioral self-regulation.

The welfare of animals in intensive farming is a contentious issue, and any objective measure of their suffering is useful in the debate. A team of veterinary scientists at Bristol University in the United Kingdom have used chickens' ability to self-medicate as proof that they suffer pain. Broiler chickens have been artificially selected to grow extremely quickly, turning food into meat at the expense of bone growth. Their legs therefore are often not strong enough to support their weight, and they frequently suffer broken leg bones. Lame birds go off their food and remain still, unwilling to walk—even to the water trough. However, 1-month-old birds can rapidly learn to select feed that contains the painkilling analgesic carprofen; in addition, the amount of painkiller the birds eat increases with the severity of lameness. Carprofen tastes slightly peppery and can cause gastrointestinal upset. Sound birds tend to avoid the drugged feed, suggesting that they find it unpleasant (Danbury, 2000).

Broiler chickens can also self-medicate stress. It has long been known that supplementing chicken feed with vitamin C (ascorbic acid) helps chickens cope better with heat stress, but producers have difficulty knowing when, and by how much, to supplement the feed. Mike Forbes and his colleagues at Leeds University in the United Kingdom solved this problem by allowing individual birds to self-medicate. To do this though, birds need some way of *detecting* the tasteless, colorless, and odorless vitamin C. Birds have acute color vision and readily learn color associations. By coloring feed that contains vitamin C, researchers revealed that birds could learn the positive effects of colored feed within 3 days and could self-medicate as and when necessary.

Kutlu and Forbes (1993) suggest that vitamin C works by reducing production of the stress hormone corticosterone, thereby reducing other symptoms of chronic stress. They point out that self-medication with vitamin C could be applied to other forms of stress such as parasite infection, high humidity, and high production rates.

MECHANISMS OF ANIMAL SELF-MEDICATION

It is clear that the behavioral repertoires of mammals and birds include many remedial strategies other than those involving the consumption of bioactive phytochemicals. The physical scraping actions of fibrous scours, the topical and local use of volatile oils, and the absorptive properties of clays illustrate the wider landscape of self-medication.

It seems we need to consider at least three nonexclusive mechanisms of self-medication:

1. Adaptive dietary/behavioral preferences—for example, adult mice have taste preferences for moderate levels of bitters that protect them from disease; deer have taste preferences for tannins that affect parasite levels. Both bitters and tannins are normally considered feeding deterrents.
2. Adaptive illness response behaviors—for example, rats seek clay when nauseous.
3. Exploratory hedonic feedback—for example, chicks rapidly learn the beneficial analgesic effects of distasteful drugged food.

APPLICATIONS OF SELF-MEDICATION

Understanding how animals attempt to self-medicate is essential if we are to provide optimal conditions for self-regulation.

Much of the self-medication we see can be explained by hedonic feedback. This ensures that animals only rarely attempt to consume highly toxic substances and prefer to consume those that confer rapid positive feedback. When it comes to finding relief from discomfort, hedonic feedback ensures that animals use safer, less potent "medicines" and resort to the stronger, often more toxic medicines only on rare occasions. This means that continuous moderate self-regulation will be more common than dramatic curative strategies using strong medicines. In other words, much self-medication is unseen.

The limits of hedonic feedback are also worth considering. Because individuals use substances that provide a

"feel good factor," they are vulnerable to intoxication and even addiction. Although not described here, both intoxication and addiction occur in wild and domestic species. Just because an animal readily consumes a certain substance does not mean that the substance is safe for consumption in unlimited quantities.

Self-medication via hedonic feedback is a fairly blunt instrument; the animal feels discomfort and tries a range of things until the discomfort is eased. This form of self-medication is aimed at relieving symptoms—not at the pathogen per se. This means that self-medication may or may not affect the pathogen. In some cases, such as when apes scour intestinal parasites, the action that removes the discomfort also removes the pathogen, but this is not always the case. Although Karban's caterpillars survived infestation with normally lethal parasitoids by self-medicating on potent alkaloids, the parasites themselves were unharmed.

It is also important to consider the role that learning plays in the refinement of self-medication strategies. Even those strategies that are apparently innate are usually refined through experience. Young male starlings, for example, have a selective preference for collecting a wide range of pungent plants at hatching time; however, the profile of those choices is refined with experience, so that older males show similar localized preferences. Chimpanzees too seem to need experience on the benefits of leaf swallowing to refine their self-medicating skills.

It is clear that birds and mammals are able to rapidly find remedies in unfamiliar compounds. Laboratory studies on pain relief and stress reduction demonstrate the readiness of rodents and birds to try novel strategies. This has management implications. In their attempt to remove feelings of unease, disease, and discomfort using what is available locally, inexperienced and poorly provisioned animals may try to self-medicate with unsuitable, even unsafe materials. It is therefore essential that safe choices be provided to them for use as potential medicines.

Health maintenance strategies are flexible but are not infallible. The ability to successfully self-medicate requires a complex mix of innate behavioral strategies and refinement attained via learning (experience). It is not appropriate to leave sick animals to fend for themselves—even free-ranging animals—in the hope that they will find some way of self-medicating, especially naïve or domesticated animals. The more opportunities animals have to learn the consequences of their actions, the better.

Domestication has not selected individuals for their ability to self-regulate, and the domestic environment often provides little opportunity for trial and error, experience with potentially toxic bioactive materials, or learning from the observations of others. Even so, given the paucity of research in this area, it is apparent from the examples presented here that domestic animals retain a surprising array of self-medicating abilities.

Incorporating our embryonic understanding of self-medication into animal health management requires that we acknowledge the individual's ability to self-regulate. This means providing individual animals with access to as many potential natural medicines as possible ad libitum. For example, although clay can provide numerous health benefits for ungulates, it is not necessarily best practice to administer clay in standardized form, say via feed, to the whole herd. This is not allowing for self-regulation. It is far better to provide clay licks for individuals to use as and when required.

The essential provision of plant biodiversity for all animals (not only herbivores) cannot be overemphasized. Exposure to diverse flora is especially important during early years when the banes and benefits of certain tastes are being developed by the individual.

Another area that veterinarians might consider is self-administration of certain drugs (herbal or non-herbal). Self-selection of appropriate levels of veterinary medication looks promising, especially for analgesia and carminatives, as long as there is no danger that hedonic feedback may lead to overindulgence.

Although more research is urgently needed, it is clear that there exists an exciting opportunity for encouraging—even exploiting—an individual's ability to self-regulate health status.

References

Abrahams PW, Parsons JA. Geophagy in the tropics: a literature review. The Geographical Journal 1996;162:63–73.

Aerts RJ, Barry TN, McNabb WC. Polyphenols and agriculture: beneficial effects of proanthocyanidins in forages. Agric Ecosyst Environ 1999;75:1–12.

Boppré M. Redefining pharmacophagy. J Chem Ecol 1984;10: 1151–1154.

Clark L, Mason JR. Effect of biologically active plants used as nest material and the derived benefit to starling nestlings. Oecologia 1988;77:174–180.

Clark L, Mason JR. Use of nest material as insecticidal and antipathogenic agents by the European starling. Oecologia (Berlin) 1985;67:169–176.

Danbury TC, Weeks CA, Chambers JP, Waterman-Pearson AE, Kestin SC. Self-selection of the analgesic drug carprofen by lame broiler chickens. Veterinary Record, March 11, 2000.

daSilveira EKP. O.lobo-guara *(Chyrsocyon brachyrus)*. Possival acao inhibidoria de certas solancas sobre o nematoide renal. Vellozia 1969;1:58–60.

Fossey D. *Gorillas in the Mist*. London: Hodder & Stoughton; 1983.

Fuerte S, Nicoladis S, Berridge, KC. Conditioned taste aversion in rats for a threonine-deficient diet: demonstration by the taste reactivity test. Physiol Behav 2000;68:423–429.

Gilardi JD, Duffey SS, Munn CA, Tell LA. Biochemical functions of geophagy in parrots: detoxification of dietary toxins and cytoprotective effects. J Chem Ecol 1999;25:897–919.

Glander KE. Nonhuman primate self-medication with wild plant foods. In: Etkin N, ed. *Eating on the Wild Side: The Pharmacologic, Ecologic, and Social Implications of Using Non-cultigens*. Tucson, Ariz: University of Arizona Press; 1994:227–239.

Hart BL. Behavioral adaptations to pathogens and parasites: five strategies. Neurosci Biobehav Rev 1990;14:223–294.

Hart BL. Behavioural defence against parasites: interaction with parasite invasiveness. Parasitology 1994;109:S139–S151.

Hoskin SO, Barry TN, Wilson PR, Charleston WAG, Hodgson J. Effects of reducing anthelmintic input upon growth and faecal egg and larval counts in young farmed deer grazing chicory *(Cichorium intybus)* and perennial ryegrass *(Lolium perenne)*

white clover *(Trifolium repens)* pasture. J Agric Sci 1999;132: 335–345.

Huffman MA. Animal self-medication and ethno-medicine: exploration and exploitation of the medicinal properties of plants. Proc Nutr Soc 2003;62:371–381.

Huffman MA. Current evidence for self-medication in primates: a multidisciplinary perspective. Yearbook Phys Anthropol 1997a;40:171–200.

Huffman MA, Caton JM. Self-induced gut motility and the control of parasite infections in wild chimpanzees. Int J Primatol 2001;22:329–346.

Huffman MA, Gotoh S, Turner LA, Hamai M, Yoshida K. Seasonal trends in intestinal nematode infection and medicinal plant use among chimpanzees in the Mahale Mountains, Tanzania. Primates 1997b;38:111–125.

Huffman MA, Ohigashi H, Kawanaka M, et al. African Great Ape self-medication: a new paradigm for treating parasite disease with natural medicines? In: Ageta H, Ami N, Ebizuka Y, Fujita T, Honda G, eds. *Towards Natural Medicine Research in the 21st Century*. Amsterdam: Elsevier Science; 1998.

Huffman MA, Seifu M. Observations on the illness and consumption of a possibly medicinal plant *Vernonia amygdalina* by a wild chimpanzee in the Mahale Mountains National Park, Tanzania. Primates 1989;30:51–63.

Janzen DH. Complications in interpreting the chemical defences of trees against tropical arboreal plant-eating vertebrates. In: Montgomery GG, ed. *The Ecology of Arboreal Folivores*. Washington: Smithsonian Institute Press; 1978:73–84.

Kabasa JD, OpudaAsibo J, terMeulen U. The effect of oral administration of polyethylene glycol on faecal helminth egg counts in pregnant goats grazed on browse containing condensed tannins. Trop Anim Health Prod 2000;32:73–86.

Karban R, English-Loeb G. Tachinid parasitoids affect host plant choice by caterpillars to increase caterpillar survival. Ecology 1997;78:603–611.

Klaus G, Klaus-Hugi C, Schmid B. Geophagy by large mammals at natural licks in the rain forest of the Dzanga National Park, Central African Republic. J. Trop. Ecol 1998;14:829–839.

Kruelen DA. Lick use by large herbivores: a review of benefits and banes of soil consumption. Mam Rev 1985;15:107–123.

Kutlu HR, Forbes JM. Self-selection of ascorbic acid in coloured foods by heat-stressed broiler chickens. Physiol Behav 1993;53:103–110.

Kuzmin A, Semenova S, Zvartau EE, Van Ree JM. Enhancement of morphine self-administration in drug naïve, inbred strains of mice by acute emotional stress. Eur Neuropsychopharmocol 1996;6:63–68.

Mahaney WC, Aufreiter S, Hancock RGV. Mountain gorilla geophagy: a possible seasonal behavior for dealing with the effects of dietary changes. Int J Primatol 1995;16:475–488.

Mahaney WC, Hancock RGV, Aufreiter S, Huffman MA. Geochemistry and clay mineralogy of termite mound soils and the role of geophagy in chimpanzees of Mahale Mountains, Tanzania. Primates 1996;37:121–134.

Mayer W. Feat of clay. Wildlife Conservation Magazine, June 1999.

McMahon LR, McAllister TA, Berg BP, et al. A review of the effects of forage condensed tannins on ruminal fermentation and bloat in grazing cattle. Can J Plant Sci 2000;80: 469–485.

Murie A. *The Wolves of Mount McKinley*. Washington DC, US Department of the Interior. Fauna Series 1944;5:59.

Niezen JH, Charleston WAG, Hodgson J, Mackay AD, Leathwick DM. Controlling internal parasites in grazing ruminants without recourse to anthelmintics: approaches, experiences and prospects. Int J Parasitol 1996;26:983–992.

Ohigashi H, Huffman MA, Izutsu D, et al. Toward the chemical ecology of medicinal plant use in chimpanzees: the case of *Vernonia amygdalina* Del. A plant used by wild chimpanzees possible for parasite-related diseases. J Chem Ecol 1994;20: 246–252.

Provenza FD. Post-ingestive feedback as an elementary determinant of food preference and intake in ruminants. J Range Manage 1995;48:2–17.

Provenza FD, Buritt EA. Self-regulation of polyethylene glycol by sheep fed diets of varying tannin concentrations. J Anim Sci 2000;78:1206–1212.

Provenza FD, Villalba JJ, Cheney CD, Werner SJ. Self-organisation of foraging behaviour: from simplicity to complexity without goals. Nutr Res Rev 1998;11:199–222.

Ramsey NF, Van Ree JM. Emotional but not physical stress enhances intravenous cocaine self-administration in drug-naïve rats. Brain Res 1993;608:216–222.

Rodriguez E, Wrangham RW. Zoopharmacognosy: the use of medicinal plants by animals. In: Downum KR, Romeo JT, Stafford H, eds. *Recent Advances in Phytochemistry 27: Phytochemical Potential of Tropical Plants*. New York: Plenum Press; 1993:89–105.

Rogers W, Rozin P. Novel food preferences in thiamine-deficient rats. J Compar Physiol Psychol 1996;61:1–4.

Sapolsky RM. Junk food monkeys. London Headline 1998:156.

Scales GH, Knight TL, Saville DJ. Effect of herbage species and feeding level on internal parasites and production performance of grazing lambs. N Z J Agric Res 1994;38:237–247.

Schaller G. *The Deer and the Tiger: A Study of Wildlife in India*. Chicago, Ill: University of Chicago Press; 1967.

Schaller G. *The Year of the Gorilla*. Chicago, Ill: University of Chicago Press; 1964.

Schreurs NM, Lopez-Villalobos N, Barry TN, Molan AL, McNabb WC. Effects of grazing undrenched weaner deer on chicory or perennial ryegrass/white clover on the viability of gastrointestinal nematodes and lungworms. Vet Rec 2002;151: 348–353.

Shlyahova AV, Vorobyova TM. Control of emotional behaviour based on biological feedback. Neurophysiology 1999;31:38–40.

Strier KB. Menu for a monkey. Natural History, 1993.

Stuart MD, Greenspan LL, Glander KE, Clarke M. A coprological survey of parasites of wild mantled howler monkeys. J Wildlife Dis 1990;26:547–549.

Stuart MD, Strier KB, Pierberg SM. A coprological survey of wild muriquis *Brachyteles arachnoids* and brown howling monkeys *Aloutta fusca*. J Helminth Soc, 1993.

Takeda N, Hasegawa S, Morita M, Matsunaga T. Pica in rats is analogous to emesis: an animal model in emesis research. Pharmacol Biochem Behav 1993;45:817–821.

Valderrama X, Robinson JG. Seasonal anointment with millipedes in a wild primate: a chemical defense against insects? J Chem Ecol 2000;26:2781–2790.

VerheydenTixier H, Duncan P. Selection for small amounts of hydrolysable tannins by a concentrate selecting mammalian herbivore. J Chem Ecol 2000;26:351–358.

Villalba JJ, Provenza FD. Nutrient-specific preferences by lambs conditioned with intraluminal infusions of starch, casein, and water. J Anim Sci 1999;77:378–387.

Vitazkova S, Long E, Glendinning J. Mice suppress malaria infection by sampling a "bitter" chemotherapy agent. Anim Behav 2001;61:887–894.

Wrangham RW. Feeding behaviour of chimpanzees in Gombe National Park, Tanzania, In: Clutton-Brock TH, ed. *Primate Ecology*. New York: Academic Press; 1977:504–538.

Wrangham RW. Leaf swallowing by chimpanzees, and its relation to a tapeworm infection. Am J Primatol 1994;37:297–303.